THE CAPITAN "REEF" REVISITED

(This is a much-expanded version (2020) of a discussion of the same locality found in the Field Guides 2016 section)

LOCATION

Located in both Texas and New Mexico, the best exposed parts of the Capitan Reef can be seen in the Guadalupe Mountains. The reef can be followed for some 40 miles on the northwest side along US 62 and 180 between White's City (near Carlsbad, New Mexico) and the dramatic El Capitan Peak of the Guadalupe Mountains National Park (Figure 1, 2). One of the best exposures is at McKittrick Canyon (Figure 2) whose entrance is just west of the NM-TX state line along US 62 and 180. There you can gain access to the Permian Reef (Capitan Reef) geology trail that climbs up 2000 feet through the reef in 3.5 miles. For viewing a contact between gypsum and dolomite in the backreef Queen Formation (Figure 19), look north at the cliff seen at the junction of highways 137 and 401, approximately 12 miles east of Carlsbad. For a cliff of pisolith, go approximately 1.5 miles, just past the first major turn to the left along Highway 7 as you go from White[']s City to the Carlsbad Caverns Visitor Center. The pisolith is in the cliff across the creek bed to the left (south) of the highway. Teepee structures can be seen in many places such as the NW corner of the parking area at the Carlsbad Caverns Visitor Center. A good megabreccia in a road cut is seen along highways 180 and 62, 1.2 miles SW of the main road entrance to McKittric Canyon, GPS about **31.9315 – 104.7311.**

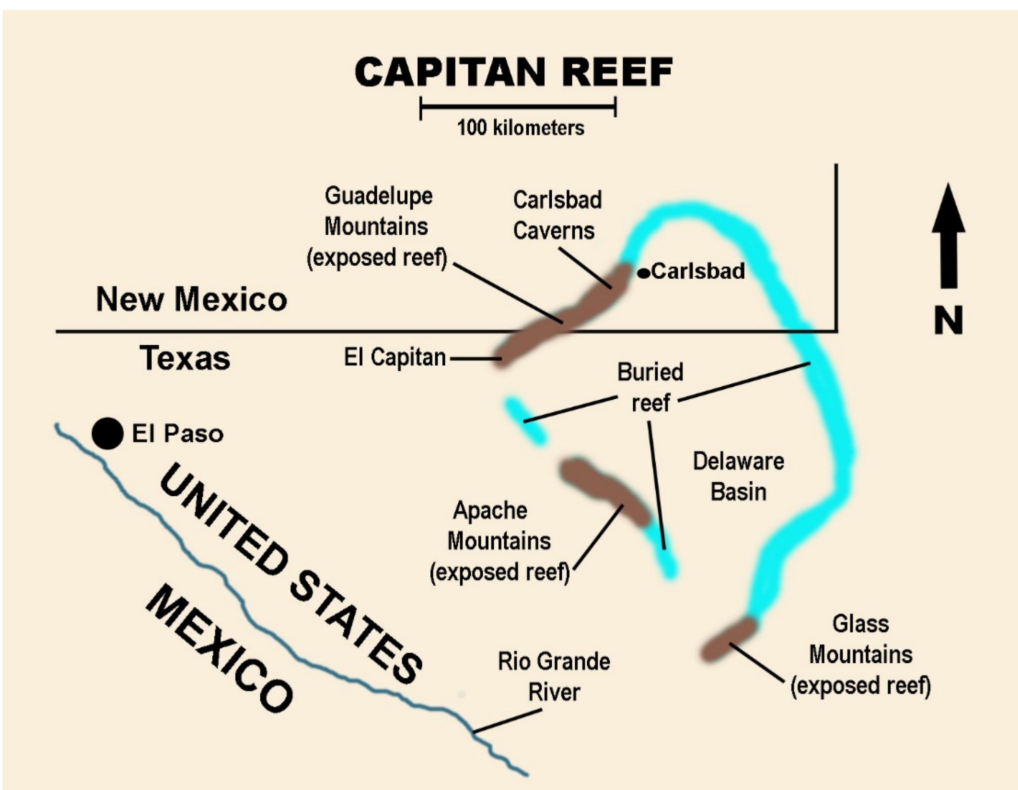

Figure 1. Map of the Capitan reef area. The proposed reef is the brown and blue regions surrounding an ocean on the inside (Delaware Basin) with an outlet at the south region (bottom open area).

Also of interest at this locality is the famed Carlsbad Caverns, endowed with stunning speleothems (stalactites and stalagmites). Speleothems can grow inches per year when provided with the right dissolved minerals, and desiccation. The present dominantly dry speleothems of Carlsbad Caverns indicate that there was more moisture in the region in the past, implying faster growth than at present. The caverns were dissolved out of the massive upper part of the reef called the reef core, probably by sulfuric acid derived from hydrogen sulfide gas.[1] During the warmer seasons you can see hundreds of thousands of bats flying out of the caverns at sundown time.

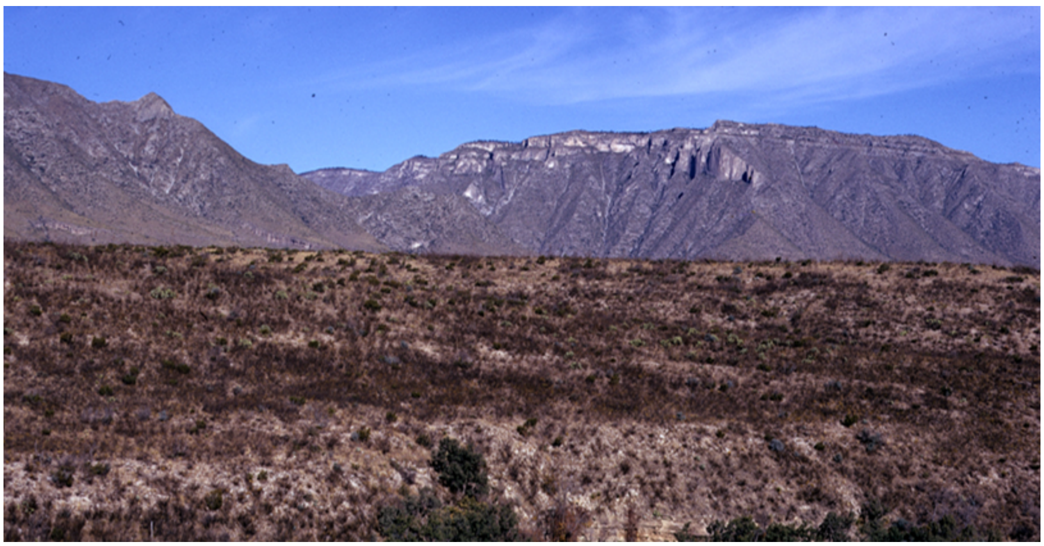

Figure 2. View to the north of the Guadalupe Mountains. The Capitan Reef is located in the hills seen in the upper half of the picture, the lower half represents basin deposits.

GENERAL DESCRIPTION

The Capitan Reef, also known as the Permian Reef, is one of the most studied, and most controversial, fossil reefs. It is a huge structure, over 100 miles in diameter. Geologists propose that it surrounded a restricted ocean on the inside (Figure 1, Delaware Basin). Most of it is now underground, but due to partial uplift, much later after formation, which created the Guadalupe Mountains, part of it can be viewed and studied more carefully above ground (Figure 2). The reef does not follow the same detailed structure as seen in the Guadalupe Mountains when followed around its entire perimeter. What you see in the hills, extending from El Capitan peak to almost Carlsbad, is part of the northwestern segment of the reef. (Figure 1). The rest is mainly to the south in Texas. As you travel along US 62 and 180 including the road leading to McKittrick Canyon, or at similar canyons along the reef, you are on the postulated ocean side, which is inside the perimeter of this huge reef. The back reef and lagoon would be on the outside of the circular reef. The ocean is considered to have been open to a larger ocean at a wide gap in the reef near its southern tip (Figure 1).

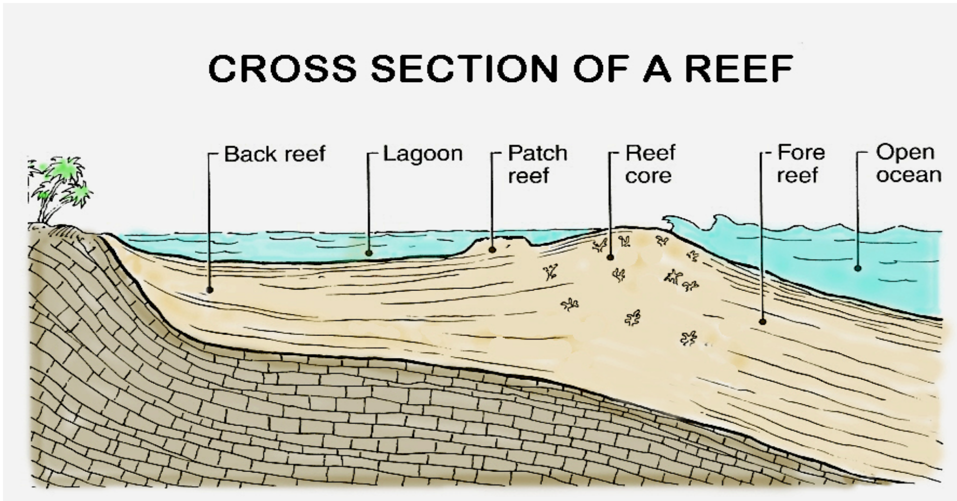

Figure 3. Cross section of a modern living reef. The reef is the light tan deposits which are produced mainly by living corals and algae growing at the surface of the reef core.

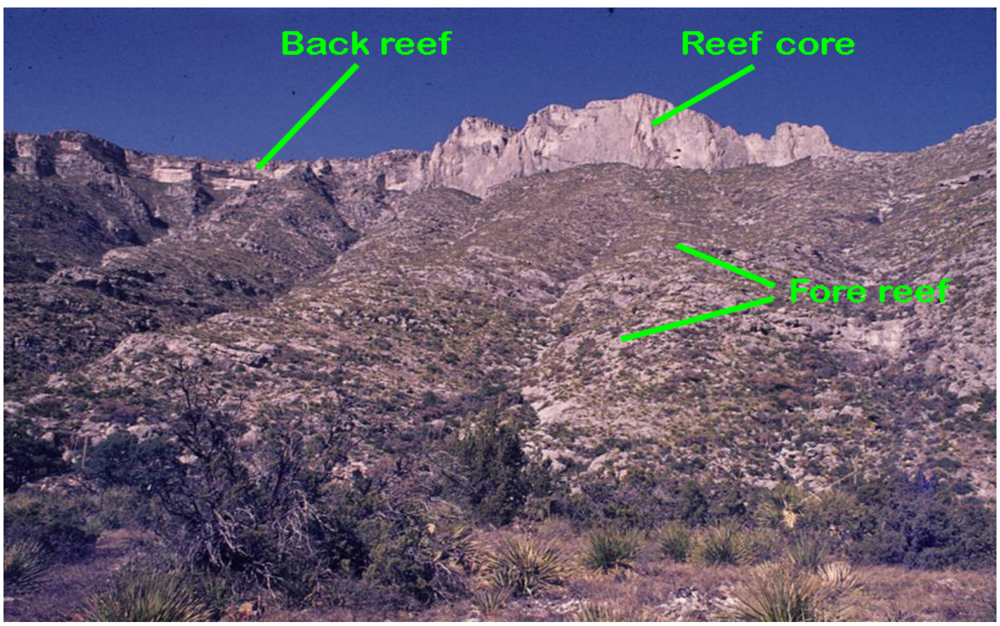

Figure 4. View to the east of the Capitan Reef from McKittrick Canyon. For the proposed relationship of the parts designated above to a modern reef, see Figure 3. Note the many extended layers sloping down to the right in the fore reef. In a normal reef interpretation these are assumed to have been produced by the reef core.

The structure of a modern living reef is illustrated (Figure 3) to facilitate comparison with the Capitan Reef. Note the location of the back reef (also called shelf or backreef), reef core (also called reef massif), and fore reef (also called forereef or reef slope) on both figures 3 and 4. The massive pale cliff at the top in Figure 4 is the reef core that is the postulated main source of the backreef and forereef deposits. El Capitan peak to the southwest, is considered to be part of the forereef, the reef core lying just a little to the north of that famous peak. Representation of the geologic formations associated with the reef is shown in Figure 5. The Capitan Reef and Capitan Forereef parts are often combined into what is called the Capitan Formation.

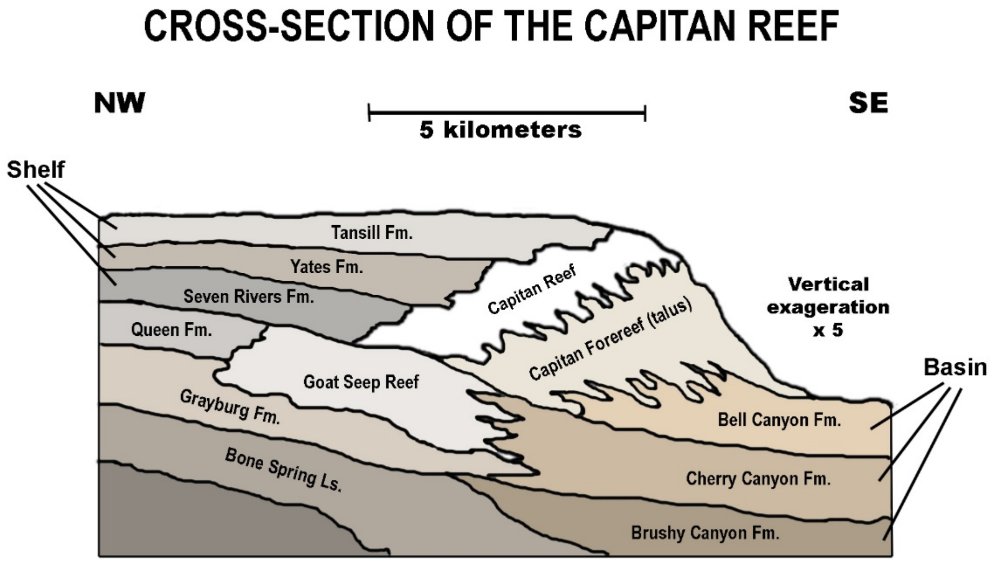

Figure 5. Representation of the formations associated with the Capitan Reef as seen in a general cross section. Note the 5X vertical exaggeration.

"The magnificent El Capitan is as controversial as it is classical."[2] There are many important disputations about this reef.[3] At least four basic models about how the reef is assumed to have existed have been proposed (Figure 6): (1) Some favor an uninterrupted slope from backreef through the reef core to the forereef.[4] (2) Others favor an arresting reef core structure reaching sea level.[5] (3) Some argue that the reef never was above sea level, with shoaling at a pisolite shelf in the backreef region.[6] (4) Others favor sea level barriers close to the sea.[7] To this list can be added the model that the reef was deposited rapidly during the worldwide catastrophic Genesis Flood. That model will be included in this discussion.

In models A ,C, D, (Figure 6) the backreef ends up at a higher level than the reef that is postulated to have produced it. That suggests uphill sedimentation. How the reef core was produced is also an enigma. That core is essentially massive, unlayered fine lime mud with a minor component of fossil sponges, bryozoans (moss animals), and or possible algal lamina and tubes; both of these latter are odd and ones have problematic biological classification affinities. A few other organisms are found including rare coral. More recently, the present trend of suggesting that all kinds of fine sedimentary layers, called microbialites, that are thought to be produced by microorganisms, has been added to the Capitan discussion.[8] Sequence stratigraphic concepts, which are based on interpretations of slow cyclic changes, were applied to the Capitan Reef long before such studies became popular in sedimentology. Both general and detailed cyclic sequence stratigraphic studies of the Capitan Reef have been controversial.

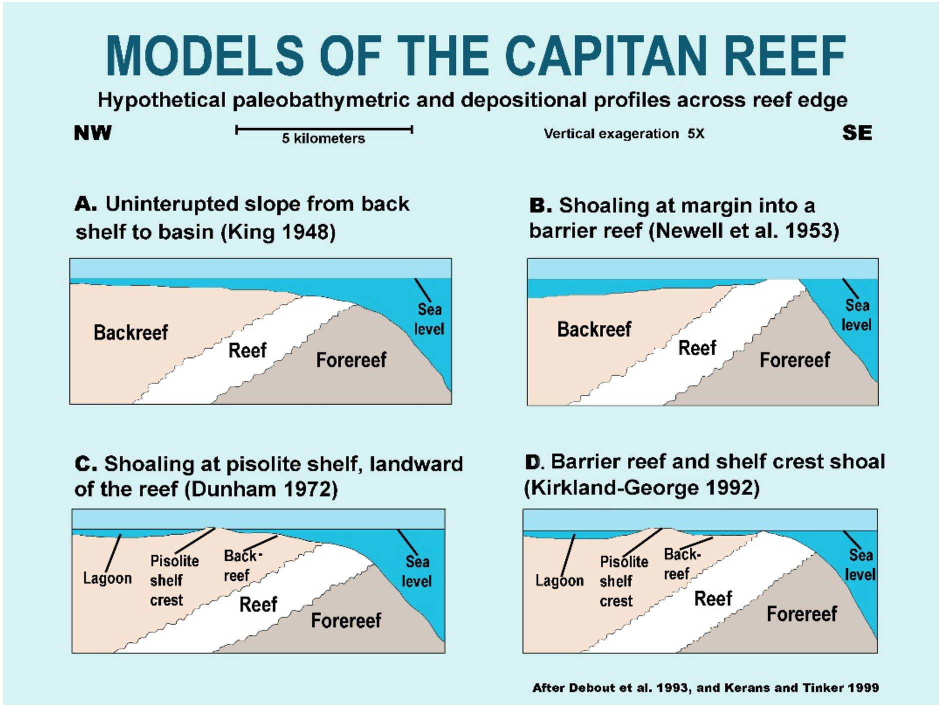

Figure 6. Four proposed models for the Capitan Reef.

DISCUSSION OF SPECIFIC FEATURES

Having a reef that would take several million years to grow in the middle of the geologic layers (Permian) does not fit at all with the creation model of a Genesis Flood as the main causal agent of fossils. The most reef-like feature of the Capitan Reef is the relation of the massive reef core that lies on top of slanting layers representing the forereef layers that the core would have produced (Figures 4.) In modern living reefs, the forereef is produced by the organisms in the core (Figure 3). However, there are major problems in trying to interpret the Capitan Reef as a real reef.

FOREREEF AND BASIN DEPOSITS

In extant reefs, the forereef is produced by calcifying organisms of the reef. The ensuing carbonate sediments migrate downslope slowly forming the sloping layers of the forereeef. Several lines of evidence suggest that rapid catastrophic activity may be involved in forming the forereef of the Capitan Reef: (1) When you look at the forereef (Figure. 4), you note a strong bedding pattern of layers downslope toward the right. This is not what you would expect from slow gradual accumulation of sediments produced by the reef core over millions of years. The extended beds suggest rapid lateral (downslope) transport. (2) In fact lots of turbidites, that are produced essentially instantly, as well as rapid debris flows, are reported for the forereef.[9] (3) Brecciated deposits are noted in forereef deposits in McKittrick and Slaughter canyons (Figure 7). These sharp angular brecciated (broken) particles are more of what is expected from catastrophic deposits than from rock particles rounded by wave activity around a reef, however, not all of the forereef is brecciated. Sedimentologist Collin Braithwait has studied the reef talus (i.e. forereef) of several major fossil reefs including the Capitan Reef and concludes that these are not the result of slow accumulation of sediments, He states "During low sea-level stands, the margin of platforms commonly become unstable, with instability reflected in slope failure and the shedding of blocks, ranging from meters to kilometers in diameter, associated with the generation of debris flows and turbidites."[10] While his proposed low sea level changes as the primary cause, does not agree with the catastrophic Flood model, the data from the rocks does.

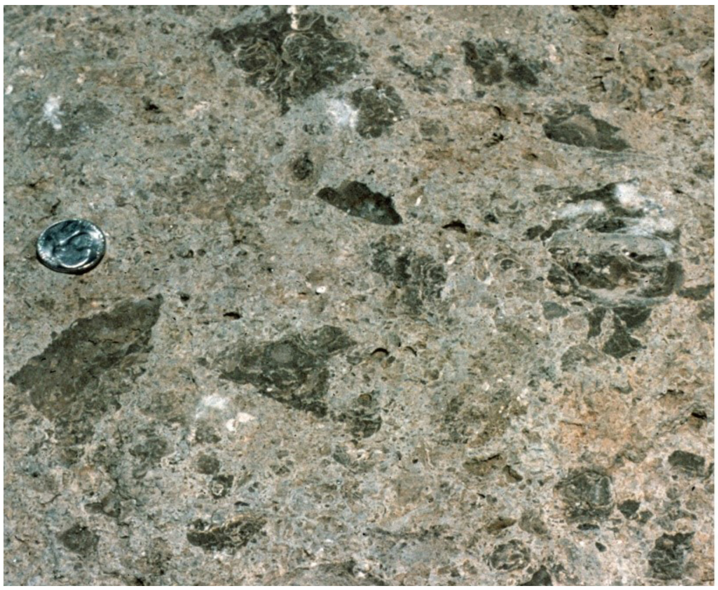

Figure 7

Breccia in the forereef seen at the foot of Slaughter Canyon. Note the angular fragments of rock, and the coin at the left for scale.

In the basin deposits, at the foot of the forereef, one sees further data that favors a catastrophic interpretation. For the standard reef model, the reef (reef core) is assumed to produce the majority of the carbonate sediments for the reef, forereef, backreef, and basinal deposits. An incongruity of the Capitan Reef is the abundant sandstone deposits, especially in some of the forereef deposits (Figure 8). Reef cores produce carbonate (limestone) minerals, so the siliceous sandstone is assumed to have come from the backreef or more likely beyond that. Some suggest that when the sea level was high, limestone was produced for the forereef, while at lower sea levels sandstone type sediments were carried across the reef core to the forereef and basin. Since there is very little siliceous sand in the reef core, one can wonder how so much of it traveled over a widespread area of the reef without being trapped by the backreef and the rough topography of a growing reef core. Channels through which it might have traveled are notoriously scarce in the reef core. In the basin deposits one occasionally sees megabreccias, which also reflect catastrophic activity (Figures 8, 9.)

Figure 8. A megabreccia in the Capitan basin. The large grey limestone blocks are "floating" in tan sandstone layers of the Bell Canyon Formation at the foot of the Capitan Reef. This is the northwest face of a road cut along US Highway 180 and 62, located about 1.2 miles southwest of the road that leads into McKittrick Canyon. GPS is about 31.9315 – 104.7311.

Figure 9. Details of Figure 8. The two whitish-gray, roundish, masses near the top are limestone blocks of a megabreccia. They are about three feet in diameter.

CAPITAN REEF proper, Figures 5. 6 (also called the REEF CORE, Figures 3, 4)

The reef core is the leading structure for reef growth. This is the proposed source for much of the carbonate sediments that dominate the region. However, some note that proposed ancient reefs appear to be different from modern reefs. A recent reference notes the different kinds of organisms found in each.[11] A book by three leading sedimentologists states:

> Closer inspection of many of these ancient carbonate “reefs” reveals that they are composed largely of carbonate mud with the larger skeletal particles “floating” within the mud matrix. Conclusive evidence for a rigid organic framework does not exist in most of the ancient carbonate mounds. In this sense, they are remarkably different from modern coral-algal reefs.[12]

These differences engender the question: Since there are significant differences between modern and ancient reefs, can we be sure that what are identified as ancient fossil reefs are really reefs? Furthermore, when ancient reefs are characterized above as “skeletal particles ‘floating’ within the mud matrix;” this is exactly what would be expected for rapid catastrophic activity proposed in this document.

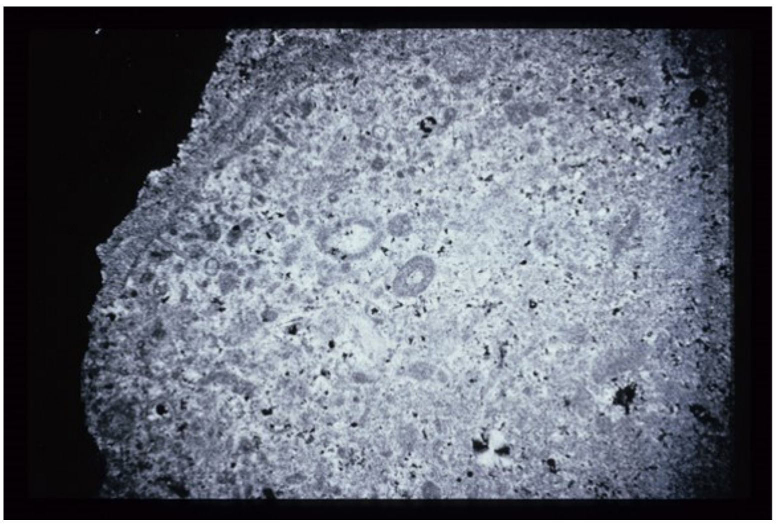

Figure 10

Microscopic view of a typical sample from the Capitan Reef core. Note spherical fossils and abundance of fine sediment particles.

The figure is about 5 millimeteres wide

Our modern reefs are built mainly by coral and algal organisms that provide a wave resistant framework that can facilitate the capture of finer sediments. However, major storms can easily rid a reef of finer sediments, and studies indicate that the bulk of these finer sediments end up in the backreef.[13] This is especially significant for the Capitan Reef core that has a dominance of fine sediments (Figure 10), and a few organisms such as sponges (Figure. 11) and bryozoans that might be considered frame builders. This is also a disputed point.[14] Some suggest the reef grew in deep calmer waters below wave level, but you still need organisms that build reefs, and sponges and bryozoans are very unlikely candidates because at present they are not known to build any significant reef structures. Yet the Capitan Reef is sometimes called a sponge reef, because there is little else that might qualify as frame builders. Furthermore, coral fossils are very rare and sponges are sparsely distributed. One study reports that about 76% of the reef consists of various kinds of fine lime mud, while sponges, bryozoans, and other large organisms form only 5.4%, and this is considered likely generous for the whole reef.[15]

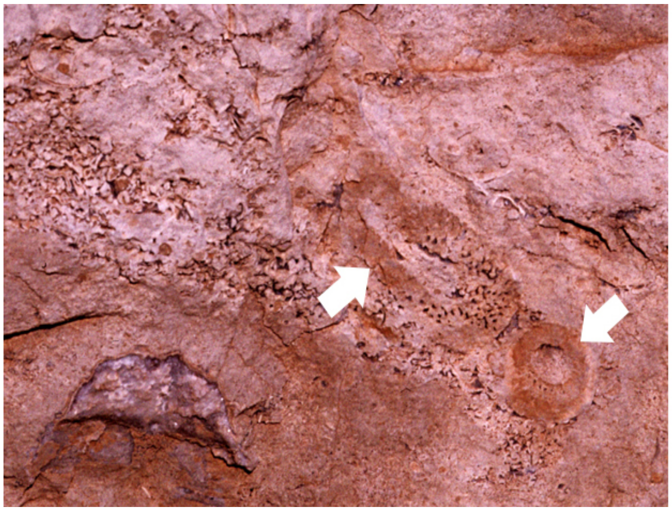

Figure 11

Fossils in Capitan Reef rock.

Longitudinal section (left arrow), and cross section (right arrow), through sponges.

Sponges around 3 cm in diameter.

There are many differing views as to how the reef core formed. The following quotation from a field guide for the area illustrates this.

> Workers who saw a dominance of wackestone concluded that the Capitan was a massive carbonate buildup ("Stratigraphic reef") but not an ecologic reef (Baars, 1964; Achauer, 1969; Dunham, 1970; Tyrrel, 1969). Others saw a dominance of syndepositional cement and concluded that inorganic cement was the critical binding agent in the reef (Schmidt, 1977; Mazzullo and Cys, 1977, 1978). Still others (Cronoble, 1974; JA Babcock, 1977; Yurewicz, 1977; Cys et al., 1977; Scholle and Halley, 1980) observed substantial amounts of organic boundstone and concluded that much of the Capitan was an organic reef.[16]

Of special concern is the origin of the dominant fine lime mud. Two leading biological suggestions are ill-defined microbial micrite from microorganisms and a possible algae called "archaeolithoporella" (Figure 12). Because of lack of details, the genus *Archaeolithoporella* is considered a problomatica, and cannot be classified. A suggestion from organisms from a distant geographical region proposes a red algae.

> Most have concluded that it is a enigmatic algae or just a problematica because of weak criteria for definition. Some have even considered inorganic. However relic cellular structures and microtubular laminae found in well-preserved specimens of Permian reefs in South China strongly support a coralline red algal affinity for the genus.[17]

Such details have not been reported for the archaelithoporella of the Capitan Reef.

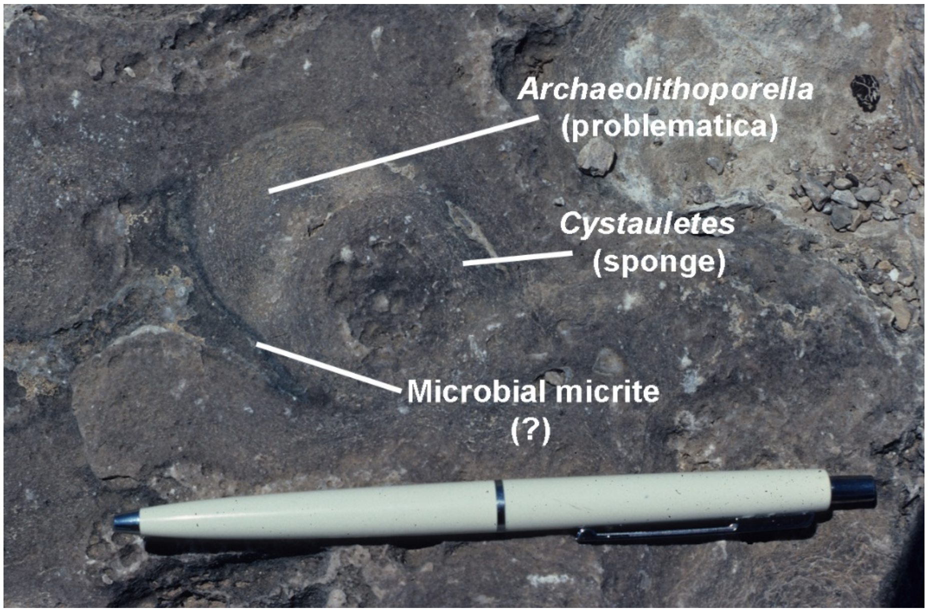

Figure 12. Close-up view of reef lime mud in the reef core. Archaeolithoporella is characterized by fine parallel ripple lines. Microbial micrite is more smooth and massive.

The suggestion that microbialites (microbial micrite) played an important role in Capitan Reef growth[18] is subject to reevaluation. The problem is not only with the Capitan Reef, but with the microbialite interpretations as a whole. This is one of those areas where speculation and fact-free science have taken inordinate control of geological interpretations. Microbialites are supposed to be sediments slowly built up by mats of microorganisms living on surfaces. The microscopic organisms trap sedimentary particles or create conditions that favor precipitation of minerals. At present, there are very few living microbialites on our globe, but all kinds of fossil microbialites are being described in the fossil record. A number that were thought to be microbialites have turned out to not be that. Reported stromatolites (a kind of microbialite) in various parts of Scandinavia have been reinterpreted as of non-biological origin.[19] A microbialite in China turned out to have abundant sponge parts, thus removing it from the microscopic organism concept,[20] In Australia, filaments thought to represent earth's earliest fossils have been reidentified as phyllosylicate minerals,[21] etc.[22] While present genuine microbialites are usually characterized by rich mats of microorganisms, these mats are seldom found in supposedly fossil ones. It is postulated that they existed but were not preserved. However, if they are not preserved, how can you be sure that the microbial mats ever existed? Rare microbe fossils are sometimes described in microbialites, hence it appears that microbes can be preserved as fossils. Why are the mats so absent? Furthermore, billions of microorganisms now live in sedimentary rocks, so just finding a few fossil ones can mean little because you don't know if they are originals or just later infiltrated microscopic intruders that happen to get preserved. Also, because of lack of data, there is lots of speculation, but little authentication that the postulated or preserved organisms had the biochemical pathways that would help precipitate sediments.

Samples of the Capitan Reef core have been examined for microbialites, and a few elongated structures that look like filaments that could trap sediments have been found. Many spherical bodies interpreted as microbes have also been reported.[23] These are 1/10 the diameter of our ordinary spherical coccus type of bacteria and half the size of the smallest known organisms, and their biological affinity is moot. Similar spheres have been reported in other limestones,[24] but a sphere shape, like a balloon or soap bubble, is a common shape, and seems unlikely to contribute much to trapping sediments. On the basis of present evidence, it seems unlikely that the Capitan Reef was built by microorganisms, or any other organisms.

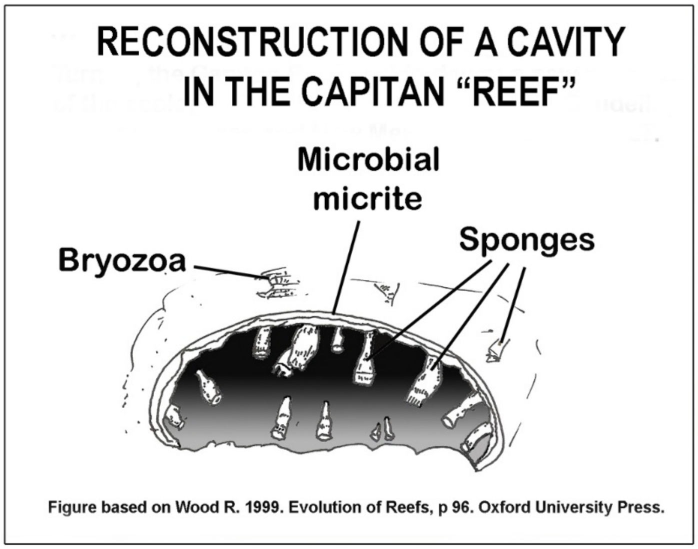

Figure 13

Proposed arrangement of sponges growing down in a cavity in the Capitan Reef.

The most abundant macrofossils (large fossils you can see) in the Capitan Reef core are sponges (Figures 11, 12). Some think they are mostly upright in position of growth, thus indicating that they grew where found and contributed to a framework for a gradually growing reef. Others have been of a different opinion. An article titled "Turning the Capitan Reef upside down" favors an upside down position for sponges as they grew down from the roof of cavities[25] (Figure 13). In a catastrophic (Flood) model, one would expect general random emplacement in all directions. Recall also that these larger organism only form 5.4% of the reef, and are unlikely to be of significance in reef building.

In attempting to show that the "reef" grew where it is located, an article in what is arguably the leading geologic journal of the world, states that 74% of the sponges in the Capitan Reef are upright.[26] With that many upright, it looks like the sponges and the reef grew where the sponges are found, having been preserved in position of growth. This was an extensive study of the reef core involving 105 polished horizontal rock slabs (Figure 14). One bit of evidence, suggested by one of the authors of the article in a personal note to Ariel Roth, provides data that would seem to favor a growing reef model. Some of the slabs show a dominance of very upright and toppled sponges, with few between those two extremes. However, these could be explained in a catastrophic context as a dominance of vertical orientation when sponges become vertical as they sink down through a sedimentary slurry. A vertical orientation would offer the least resistance as the heavier sponges sink down through a fluid.

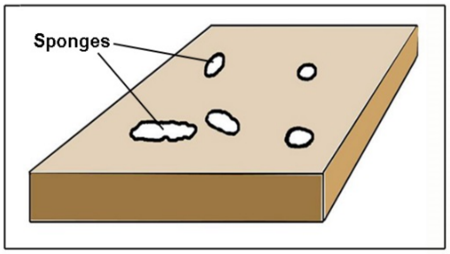

Figure 14. Representation of a horizontal slab from the Capitan Reef core with fossil sponges in cross-section.

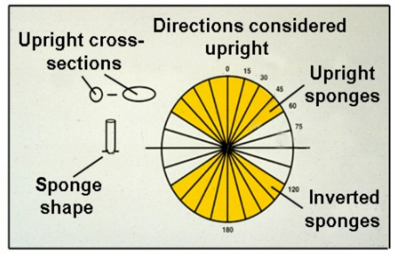

Figure 15. Vertical orientation of sponges using only cross-sections. All sponges oriented in the yellow region would be considered upright.

Three factors challenge the validity of the proposed 74% upright interpretation: (1) To determine position of growth, cross sections of the sponges were examined on the surface of horizontal slabs (Figure 14), and if the round cylindrical sponges appeared up to twice as long as wide, they were considered upright. This means that the sponges could deviate up to 60° from the vertical and they would still be considered upright. Beyond 45° from vertical, the sponges would be closer to the horizontal than vertical but would still be counted as upright. Note the yellow in Figure 15. (2) More serious is the problem that if a round sponge was bottom side up, it would still appear near round on the surface of a slab and be considered upright, thus raising the proportion of upright sponges for a random orientation sample from 33% to 67%. In Figure 15, all the sponges that happen to be oriented in the yellow region would be considered upright. (3) Then there is the bias in favor of counting vertically oriented sponges on horizontal slabs. Because of their elongated shape, it is more likely that a horizontal slab surface will intercept a vertical sponge than a horizontal one (Figure 16), thus causing an apparent inordinate number of vertical samples. These three factors explain how one can get a 74% vertical figure from a random orientation (catastrophic) sample with sponges in all directions.

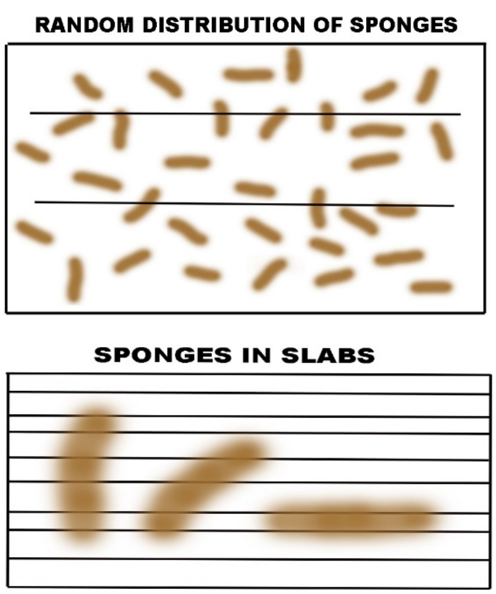

Figure 16

View of elongated sponges (tan), randomly oriented on a vertical surface. The horizontal lines (surfaces) intercept more vertical sponges than horizontal ones.

The lower view illustrates the same principle, showing that a vertical sponge is more likely to be intercepted by a horizpntal slab cut (surface) than a horizontal one. Length of sponges is around one decimeter.

In another publication by the same authors, but in different listing order, some caution is expressed. Note their reference to lack of attachment to the substrate as expected for growing sponges.

> The taphonomic history is difficult to reconstruct. Field and thin-section data suggests that a few reef builders are oriented upside-down, but do not indicate the presence of "ubiquitous" cryptic habitats. The absence of reefbuilder attachments to the substrate and the absence of sedimentological criteria indicative of crypts suggest that many specimens are toppled rather than in growth position.[27]

It appears that the sponges of the Capitan Reef are likely randomly oriented, as expected for catastrophic deposition. Never-the-less, the idea that the sponges are upright and provide a structural framework still prevails in the geologic literature.[28]

In studying the orientation of fossils, it would seem preferable to study vertical views instead of horizontal ones where the direction of orientation can be directly observed. That approach was taken in a study of fossil reefs conducted by Lance Hodges and Ariel Roth the author of this discussion.[29]

Compared to modern reefs, the Capitan Reef seems ecologically simplistic. Japtan Reef at Enewetak Atoll, a living reef in the western Pacific Ocean, has five distinct zones of organisms as you go from open sea to the lagoon.[30] This lack of organization for the Capitan Reef can be attributed in part to a paucity of kinds of organisms, but that lack underlines the problem of considering Capitan Reef a biological product. Beyond that, on our present reefs, we usually find tidal surge channels (Figure 17) and repetitive spur-and-groove structures (Figure 18.) at or near the surface, but these are essentially absent from the Capitan Reef core that is noted for lacking even bedding surfaces. While a few suggestions of detailed reef structure have been proposed for the Capitan Reef,[31] it does not look like it ever was a shoreline structure.

Figure 17

The two arrows point to surge channels on the edge of Enewetak Atoll

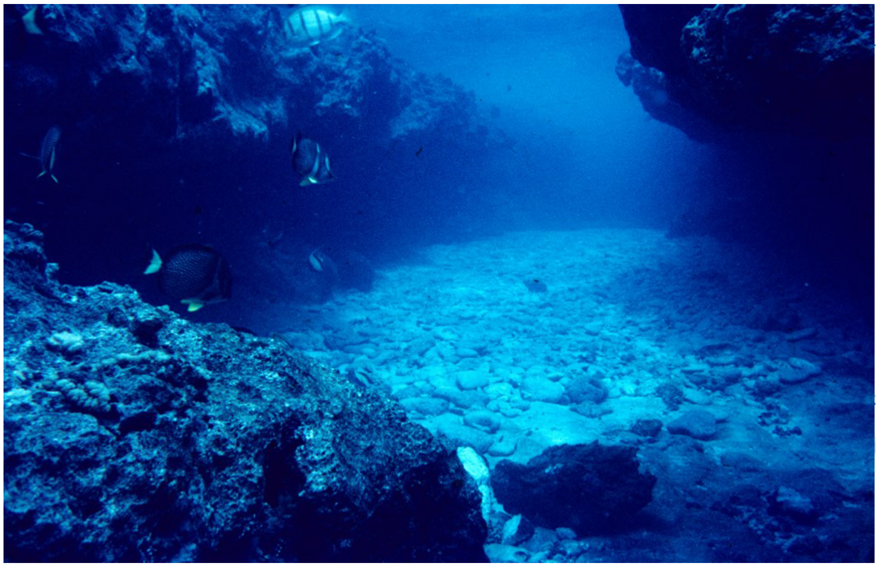

Figure 18

Spur and groove, Enewetak Atoll. The groove is the open channel, with the fish between the two spurs (walls) on either side.

Groove is a little over a meter wide.

BACKREEF QUESTIONS

There are questions about the back reef that also challenge traditional geologic interpretations. One of the more intriguing ones is the relatively abrupt change in minerals from gypsum-anhydrite (sulfates) to calcite-dolomite (carbonates) sediments in the Seven Rivers Formation. The change can be seen as you proceed northwest from the reef core across the lagoon of the back reef. This change is along at least a nine mile front, and is abrupt but often not very easy to see through surface debris. The gypsum-anhydrite is more whitish (Figure 19).

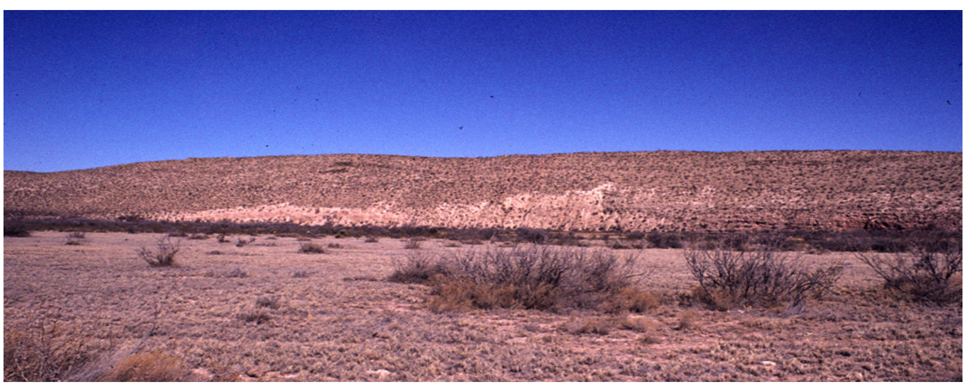

Figure 19. View of the abrupt change in sediment type in the Seven Rivers Formation. The whitish gypsum layers in the middle of the photograph changes to grayish dolomitic limestone layers to the right.

The classic exposure is along the north flank of the western end of Rocky Arroyo, about 12 miles west of Carlsbad, NM[32] (Figure 20). There, the lower part of the Seven Rivers Formation is several hundred feet thick. If you look in the erosion channels that expose the original rocks between abundant debris, you can note an abrupt change from sulfates to carbonates as you go from west to east. The broad region of changes extends laterally over some 500 feet, but locally it is much closer.

The traditional interpretation is that the calcite-dolomite was formed mainly by calcifying organisms and precipitation of lime in the reef and lagoon, while the gypsum-anhydrite were formed by shoreline evaporation of water in moist sediments as for the sebkhas (also sabkha) of the Persian Gulf. Table 1explains the scarce yields expected from evaporation, and the need for a reflux of sea water over extended time to get the thick layers seen. It has recently been suggested that dissolution (dissolving) of the sulfates may have contributed to the abrupt change,[33] but the absence of expected unrelated masses of either type would invalidate this kind of interpretation.[34] The classic sebkha interpretation has also been challenged.[35]

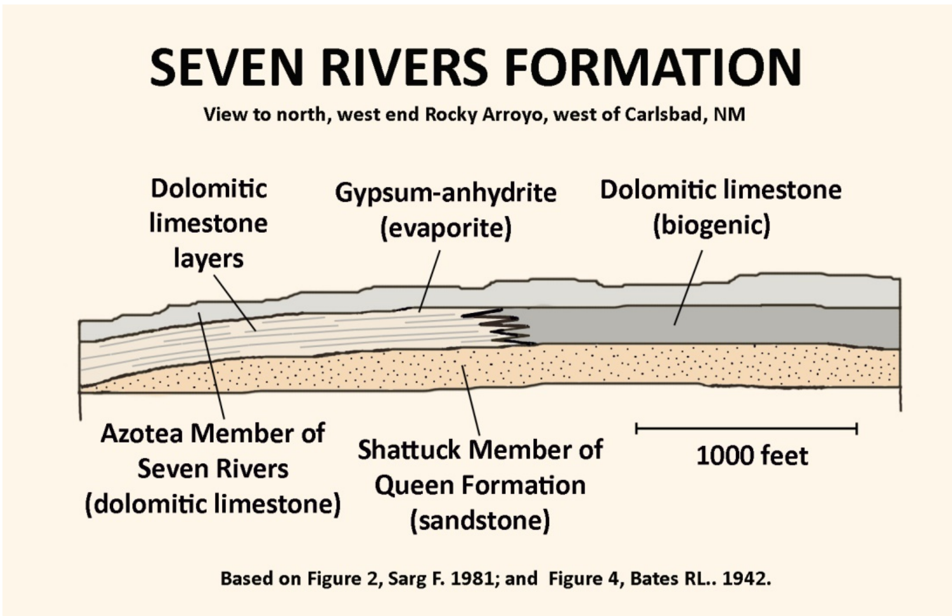

Figure 20. Abrupt change in the lower part of the Seven Rivers Formation from gypsum-anhydrite to calcite-dolomite in Rocky Arroyo, near Carlsbad, New Mexico.

Table 1. Result of evaporation of seawater

Evaporate a sample of seawater 1000 feet deep:

Seawater left	Minerals precipitated		Thickness of recovery
533-190’	$CaC0_3$, Calcite	$CaMg(CO_3)_2$ Dolomite	0.05’
190-030’	$CaSO\text{-}2H_2O$, Gypsum	$CaSO_4$ Anhydrite	0.4’
90-16’	NaCl Halite (Salt)		11.6’

Besides the major change from calcite-dolomite to gypsum-anhydrite in the Seven Rivers Formation, there are equally abrupt changes in small layers several feet thick that suddenly change from calcite to gypsum[36] (Figure 21). Furthermore, between 3-20' major layers of gypsum-anhydrite, one finds thin layers of calcite-dolomite in the thin to 2 foot thickness range (Figure 20, left half). There is frequent interfingering of the two kinds of rock types in the transition zone. To have two contrasting causes (major evaporation for gypsum versus organisms and minor evaporation for calcite-dolomite) for sediment formation so sharply delineated in the middle of a backreef region seems very unlikely. Furthermore to have that contrast in causes remain sharply delineated within a few hundred feet (Figure 20, middle) as they formed over many hundreds of thousands of years is even more unlikely. The abrupt changes in rock type within a layer and the many interfingerings of the two are difficult to reconcile with sebkhas and without invoking major sediment transport. These changes seem better explained by catastrophic transport from different sources for these two kinds of sediments. One needs to also keep in perspective that there is lots of sand in the backreef deposits, especially the Yates Formation, and this sand would not be produced by a carbonate reef core and would have to be also transported there. An alternative suggestion is that after deposition of carbonate layers, sulfuric acid contributed to the formation of the gypsum in limited areas. That model seems very unlikely because of the widespread horizontal pattern of the gypsum sediments.

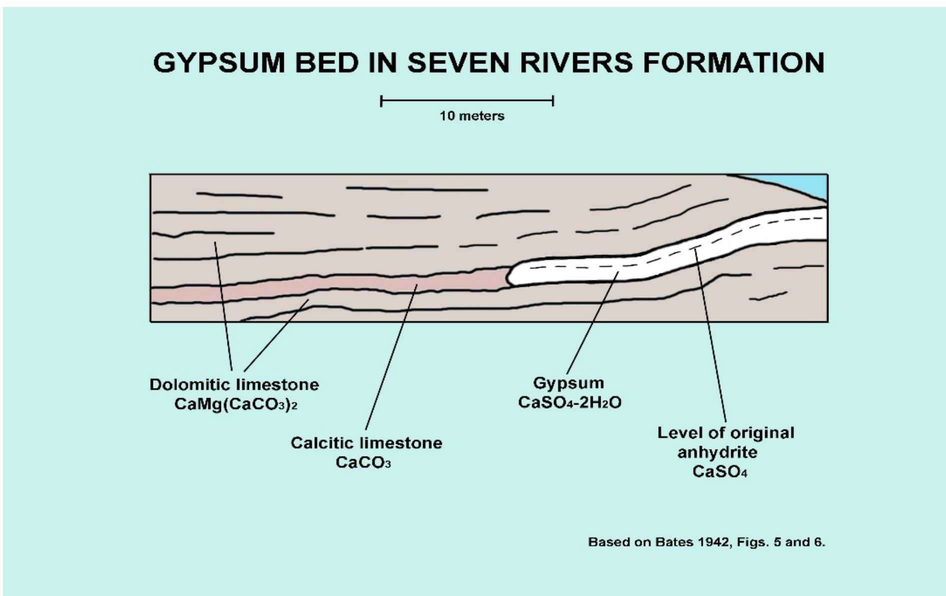

Figure 21. Abrupt contact of gypsum layer in dolomitic limestone of the Seven Rivers Formation.

Another intriguing feature of the backreef is the presence of what is called tepee structures (Figure 22). They get their name because of the remote resemblance of the layers to a tepee tent structure culminating up to a point. It may be that there has been escape of fluid, causing the layers to push up at the tepee localities. Often some sand is seen in a central vertical crack between the uplifted layers also suggesting fluid escape. There are many interpretations. In a review of the Capitan deposition A. H. Saller, et al. list and reference the following seven suggested methods of formation.[37]

1. Compression during deposition
2. Crystallization of evaporite minerals
3. Desiccation cracks
4. Thermal expansion and contraction
5. Upward moving groundwater
6. Discharging groundwaters
7. Siliciclastic sediments in core from lowstands of sea

Of the seven suggestions listed above, numbers 2-4 and 7, cannot be considered very feasible because of lack of authentication or plausibility. Numbers 1, 5 and 6, are more what would be expected in a catastrophic Flood context, and 5 and 6, that are essentially the same, explain the presence of the sand in a dominantly carbonate environment. Extrusion of excess water as sediments compacted may explain these tepee structures.

Figure 22

A tepee structure in the backreeef. The layers that bend upward towards the irregular midline of the picture are the tepee.

Total height is about 1 m.

The pisolite sediments of the backreef (Figure 6) have played a significant role in Capitan Reef structure interpretations because their elevated location may represent a reef crest. They are composed of pea size concentrically layered spheres called a pisoid (pisolith, pisolite) (Figure 23). A sequence of suggestions about how they formed follows:[38]

1. Algae growing over the surface of fine grains
2. No algal cells could be found!
3. Others: But algae did produce them
4. Others (Dunham, Thompson) produced inorganically in vadose zone. Evidence includes polygonal fitting and layers around several pisoids.
5. Composite origin from algae and inorganic precipitation
6. Probably inorganic below water sediment line.

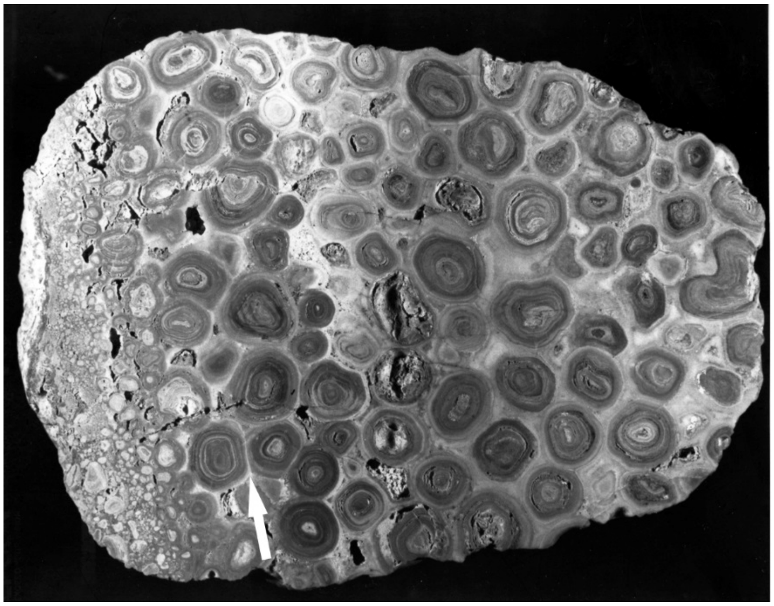

Figure 23

Polished surface of a pisolite. The arrow points to a flat contact between two pisoids indicating formation in the rock.

The largest pisoids are one cm in diameter.

The different interpretations for pisoid formation reflect various interpretations for the Capitan Reef as a whole (Figure 6). If the pisoids were formed by algae as they were rolled around, this would likely require a shallow environment, and in the context of a catastrophic flood model would require some time for growth of the algal induced layers. However, they could also have been transported from a preflood pisoid source. If they were formed inorganically by precipitation slowly after sediment deposition, a shallow origin and suggested Flood time constraints are negated. An argument in favor of later inorganic postflood formation is illustrated by the arrow in Figure 23 that points to a flat contact between two pisoids. Such contacts are called polygonal fitting and the flat layers are interpreted to represent inorganic precipitation in situ. Also note, in region of arrow, that some layers go over two pisoids, indicating later non-algal precipitation. Polygonal fitting is compatible with a diagenetic origin occurring long after sediment deposition by a catastrophic Flood.

CONCLUSIONS

Probably the most favorable data for the reef interpretation is a horizontal "reef core" that lies above a cross bedded "fore reef" with the layers dipping towards the postulated ocean basin (Figure 4). Few or no significant conclusions beyond that, about the Capitan Reef, are not disputed. The fact that interpretations are so numerous and varied indicates the lack of compelling evidence. The simple structure of horizontal layers above cross bedded layers is not diagnostic for a reef and is frequently observed in a multitude of sedimentary localities that are not interpreted as reefs.

Problems with the reef interpretation for the Capitan "Reef"

1. The lack of organisms that would build a reef is likely the most severe challenge to the reef interpretation. Our present reefs are built mostly by coral and coralline algae. The main suggested frame builders for the Capitan Reef are sponges and bryozoans, but they

form only about 5% of the reef, and these kinds of organisms are not known to produce any significant reef structures. The microbialite and *Archaeolithoporella* suggestions lack substantial authentication of an organismic identity.
2. It seems unlikely that the fine sediment particles that dominate in the reef core of the Capitan Reef would accumulate in a developing reef environment that is persistently pounded by wave breakers. Some postulate a protected deep water environment, but that is not a real "reef" as the term is commonly understood.
3. Reef core lacks reef hydrologic evidence, such as abundant surge channels and spurs-and-grooves common to our present reefs.
4. An ecological distribution of organisms expected on the edge of a reef is essentially absent for most of the reef.
5. The orientation of the sponges appears random, and not in growth position, thus suggesting they were catastrophically transported, and not in situ growth.
6. Many features of the forereef such as breccia, turbidites, debris flows, and thick widespread beds, suggest persistent catastrophic deposition, not slow reef accumulation.
7. The abundant sand found in the basin deposits is not expected from a carbonate reef source.
8. The reef core, that is the putative source of the back reef, is lower than the backreef whose layers gently rise upward as you proceed shelfward, thus challenging gravity.
9. The massive beds of the backreef and forereef are huge compared to the thin slow productive active top of a reef core that is supposed to have produced them.
10. Aberrant massive and interfingering backreef deposits of gypsum or carbonates suggests catastrophic deposition from different sources.

How was the Capitan "Reef" formed?

More study is needed!

In a Genesis Flood context, the following broad suggestions can be made, but many details need thorough evaluation and elaboration:

1. The backreef evaporite, carbonate, and sandstones now found there, represents transported sediments from varied sedimentary sources.
2. The slanting forereef layers represent activity similar to the slanting foreset beds of river deltas.
3. The massive reef core that has virtually no bedding likely represent catastrophic emplacement from a fine carbonate source.
4. Distant sources would have produced the aberrant sandstones of the backreef and basin deposit.

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